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Design and Development of Advanced Spatio Temporal Database Models

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Abstract

The researchers have presented a spatial database model for geometric path planning suitable for facilitating disaster management activities. The spatial queries executed using the proposed approach can reduce the computational time needed to find an optimal collision free path for network analysis. The framework is applicable to 2-dimensional and 3-dimensional workspaces. The strategy used decouples the motion planning problem into small tractable problems, which are solved using know path planning algorithm.

Keywords: Index terms-avoidance, Disaster management, Path planning, Query processing, Spatial database, Visibility graph.

1 | Introduction

1.1 | Geo-Spatial Database Model

To understand the real world, its characteristic features must be studied and modeled. In the real world features are described by some descriptive terms, by physical location and by their ability to connect both physically and logically to other features. Thus aroad featurel could be described by attributes (name and length), by geometry (its physical location), by topology (how it is physically connected to other. features) and by join relationships (its logical connections with other features).

1.2 | Geometric Path Planning

Geometric Path planning are geometrical methods used for computing a collision or obstacle free path connecting the initial and final point in 2D and 3D environments. Given a mapping and a description of the obstacles they provide a geometric description of the path in the workspace. Advantages of using geometrical

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descriptions are obstacles can be represented by arbitrary polygons, arbitrary motion angles. Also it is possible to find optimal paths for circular objects using topological abstractions. Successful attempts are made to reduce the computation time needed to find an optimal collision-free path for robot motions [1], [2].

1.3 | Review of Related Literature

Existing geo-spatial database models consider only fixed obstacles in 2-dimension workspace. In-2 dimensional work space motion plan from pstart to *p*end does not cross the interior of any obstacles O. Even the visibility graph is pre- computed and maintained in the memory thereby occupying the memory space. In-3 dimensional work space obstacles with significant height can be considered, since the path can go over obstacles and not just around them. Hence we need an Integrated Frame work that is applicable to 2-dimensional and 3-dimensional workspace and computes the visibility graph in a dynamic environment [3].

1.4 | Obstacle Identification

Obstacle in geometrical path planning refers to obstruction or blockage that arises in finding or traversing the path. Natural and created objects in geometric path planning problems are usually divided into moving and fixed objects called as obstacles. In many applications, physical obstacles like mountains, rivers, water logging, disaster sites etc substantially affect the geometric path planning. In our paper we have classified obstacles as natural obstacles and created obstacles. Natural obstacles are those obstacles that cannot be moved and altered such as such as rocks, sea, stream, ledges and mountains. Created obstacles are those obstacles that are formed mainly due to environmental and geographic changes such as water logging formed due to improper land elevation. Pedestrian movement, public buildings, indoor areas, vehicles navigating through narrow lanes restricting the traffic and disaster affected sites can also be classified as created obstacles. In real world most obstacles are not fixed but movable. A human planner would take into account that he can move these obstacles to solve geometric path planning problem. Ignoring these obstacles will affect the performance of geometric path planning algorithms, clustering algorithms and produce inappropriate results. Thus the ability to handle such real life constraints in a Geo-Spatial Data model is very important

1.5 | Disaster Management

Disaster management is skillful handling of crisis, danger or an unexpected situation demanding instant action which can be handled under a controlled situation in case of a juncture. It is a cycle of activities beginning with planning the Disaster Management plan, mitigating the vulnerability and negative impacts of disasters, preparedness in responding to operations, responding and providing relief in emergency. situations such as search and rescue, etc.

1.6 | Importance of Geometric Path Planning in Disaster Management System

During the disaster response phase, response activities are designed to provide disaster assistance for victims. Disaster response activities can be facilitated by providing the best route and closest facility required at the time of emergencies. Best route means the shortest, fastest geometrical path to be identified among different alternate paths available in different situations. For example, while people are affected during disaster, they need to be rescued by any means. So theselection of the quickest and shortest route to the disaster site, hospital or shelter is very important at that moment. Navigation is one of the main applications of network analysis in location based systems .In order to navigate to a destination, a shortest path analysis technique is used. The network analysis considers all possible paths and determines the shortest and quickest path to reach taking into consideration all the obstacles.

1.7 | Significance and Objective of the Study

One of the challenges considered for the effective and efficient implementation of disaster management is.

I. No access or limited access to and usage of reliable, accurate and up-to-date spatial information for Disaster Management.

II. Disaster Management activities are carried out in isolation and no efforts are made to optimize the data or information for improved decision making.

For example:

The factors affecting disaster management: lack of timely up-to-date information, lack of accurate spatial information describing the situation (available resource, access to roads, damaged areas, required resource and required responding operations), lack of sharing of information between involved parties, lack of synchronization between involved parties, highly dense populated areas. These factors resulted in Uncertainties at every stage decision, there by introducing Information errors.

This model will present the overall structure, concept and advantages of facilitating disaster management activities using the Geo-Spatial data model.

1.8 | Geographical Region Under Study

The mumbai metropolitan region has a total area of 4355 square kilometer, consisting of 1273 square kilometer urban area [4]. The Urban region has a population of 17.7 million, out of the total population of 18.9 million. Mumbai is divided into 13 wards. Mumbai D Ward is selected as study area. The ward covers an area of 6.63 square kilometers. The approximate population of the ward is 3, 99,931(as per 1991 census) with an additional day-time floating population of 1, 00,000. D ward has 23 buildings that are old and are identified as dilapidated and dangerous for occupation. The ward is selected as it covers historical, religious and tourist'scenters. The ward also covers slum affected by floods. The ward is also made up of low-lying areas that are affected by flooding. In 2005 floods claimed almost 1,100 lives in the state, most of them coming from urban concentrations of Mumbai and Thane [5].

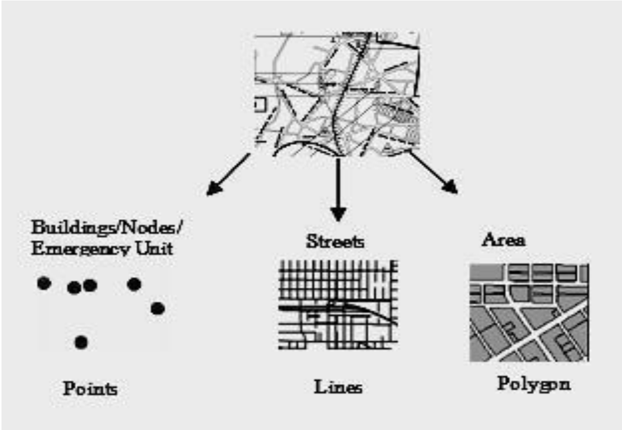
2 | Problem Definition

$_s$Our$_s$, problem can$_s$, be specified as follows: Given $_{M^n}$ a $S_M$et $O = \{o_1, \ldots\ldots\ldots o_n\}$ of fixed obstacles, a set $O = \{o^1, \ldots\ldots\ldots o_m^M\}$ of moving obstacles and a moving object o^m with start configuration c^{start} and goal configuration c^{goal}, compute a collision free motion p^M for o^m with respect to O^s and O^M and a motion plan MP i.e. a sequence of coordinated collision free (with respect to all the objects in the scene) motion for object o^M . So that p^M becomes collision free considering O^s U O^M after executing MP. We utilize the findings for efficient spatial query processing in the presences of obstacles. The spatial database model developed is applicable disaster management system in a dynamic environment.

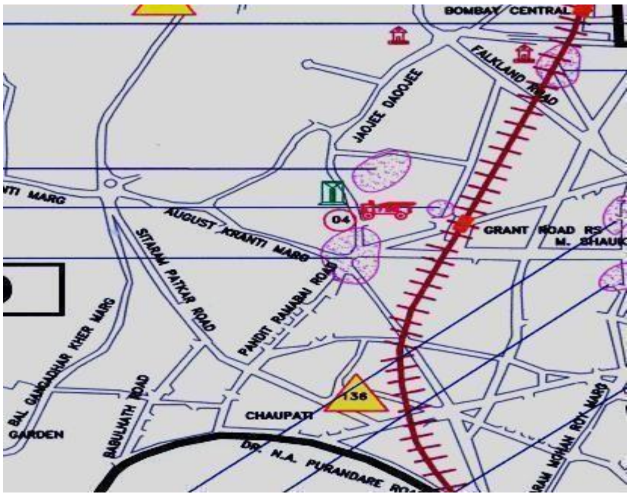
3 | Methodology Adapted

3.1 | Creation of Spatial Data

The spatial data required for the current study was prepared by referring to the landuse/settlement map of Mumbai D ward [6], the mumbai island city disaster management plan and other maps on various themes of the area. The mumbai island city disaster management plan on 1: 25,000 scales has been digitized using scanning technique. The map being on the scale of 1: 25,000 the minutes details missing, were plotted referring to the satellite map and other land use map/settlement map of D Ward. The real world entities from the map were abstracted into three basic shapes: nodes, arc and region. The streets were identified as arcs and the areas as polygon. The roads are a combination of multiple arcs. Each are has a start node and anend node. Each node has been assigned a unique id and the coordinates for each node id is obtained using the graph theory. The spatial relationships between points, arcs and areas are then expressed using topology as shown in *Fig. 1.a.* Adjacency matrix, incidence matrix and coverage data structure is prepared using topology.



a.



b.

Fig 1. a. Topological features; b. Map of study area-mumbai D ward.

Using the information of adjacency matrix and incidence matrix the coverage data structure is prepared. The coverage model incorporates the topological relationships intothe structure of feature data. The coverage data model is prepared for the points and lines in the study area from the digitized map and the satellite map. To make the digitized map usable it is converted into a projected coordinate system. Affine Transformation is used to implement the following geometric transformations:

$$X = Ax + C, Y = Dx + Ey + f. \tag{1}$$

where x, y are the input coordinates obtained from *Fig. 2* and *Fig. 3* and X, Y are the new user projected values respectively represented in *Fig. 4*. The transformations coefficient A, B, C, D, E, and F are calculated using the following matrix equation:

$$\begin{pmatrix} n & \sum y & \sum y \\ \sum x & \sum x^2 & \sum xy \\ \sum y & \sum xy & \sum y^2 \end{pmatrix} \begin{pmatrix} \sum X & \sum Y \\ \sum xX & \sum xY \\ \sum yX & \sum yY \end{pmatrix} = \begin{pmatrix} C & F \\ A & D \\ B & E \end{pmatrix}. \tag{2}$$

where n is the number of control points. Substituting the values of n, $\sum x, \sum y, \sum x^2, \sum xy, \sum y^2, \sum X, \sum Y, \sum xX, \sum yY, \sum yX, \sum yY$ in *Eq. (3)* the values of transformation coefficient A, B, C, D, E, F are obtained. The values of A, B, C, D, E, F, x, y are substituted in *Eq. (1)* and the new user coordinates X and Y obtained are shown in *Fig. 4*. They represent the actual coordinates for each node. The

deviations between the computed X and Y coordinates values and the initial x, y values are calculated using root mean square error method. The average RMS error can be computed by averaging errors from all control points.

$$\{[\sum_{i=1}^{n}(X_{act,i} - x_{est,i})^2 + \sum_{i=1}^{2} y_{act,i} - Y_{est,i})^2]^{1/2}\}/n. \quad (3)$$

where n is the number of control points, x act, i and y act,i are the x and y values of the actual location of control point i, and x est, i and y est, i are the x and y values of the estimated location of the control point i. The average RMS error in the present study is 2.379121. Since the average RMS error is < 6 the values of X, Y are acceptable. A spatial database is created presenting the data structure, path list, and arc-node list for ward region. disaster prone region, and the roads. Impedancesmatrix of the travel time between nodes on a network is also prepared.

3.2 | Integrated Framework

The strategy used for developing the spatial database model uses four major steps:

I. Identifying the set of movable obstacles: we first identify a set fixed obstacles: we first indentify a set $O^s = \{o^s_{1,} \dots \dots \dots \dots \dots o^s_n\}$ of fixed obstacles and a set $O^M = \{o^M_{1,} \dots \dots \dots \dots \dots o^M_m\}$ of moving obstacles from the set of obstacles $O = \{o_1 \dots \dots \dots . o_n\}$.

II. Compute paths for moving collision free with respect to fixed obstacles: In this step the moving obstacles are ignored and visibility graph G is computed for the moving object considering only the static obstacles.

III. Determine the set of moving obstacles obstructing the previously computed paths: Using the result of step I and 2 we identify the obstructing moving obstacles. The result is set O^Mcol subset of $O^M$of colliding moving obstacles.

IV. Independently compute paths for obstructing moving obstacles which clear the paths of the moving obstacles: the colliding moving obstacles O^M needs to be moved at different location to clear the path for o^m. We independently compute visibility graph G_1 for obstructing moving obstacle which will clear the path for o^M.

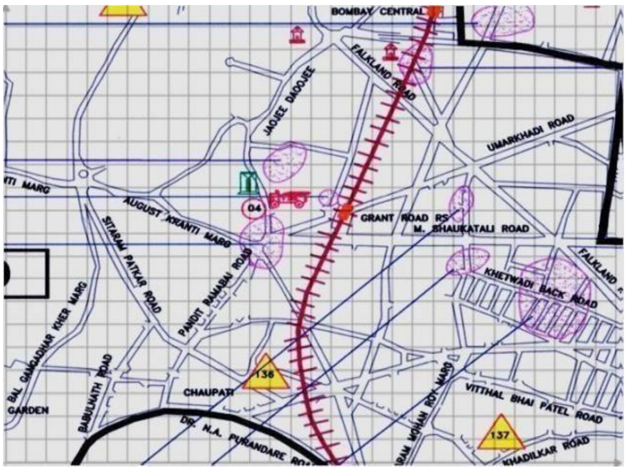


Fig. 2. Actual coordinates.

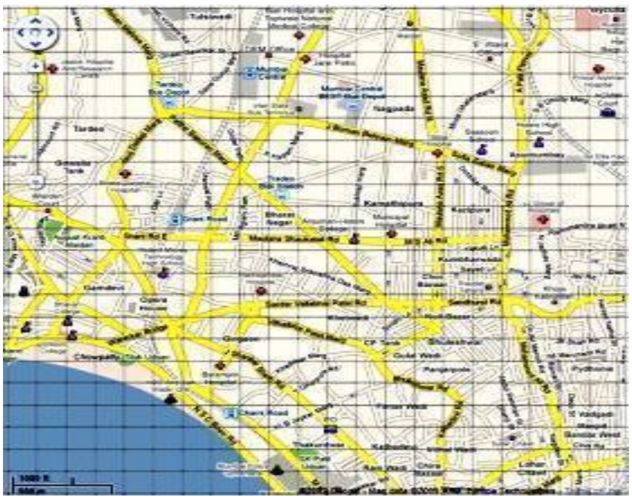


Fig. 3. Real coordinates.

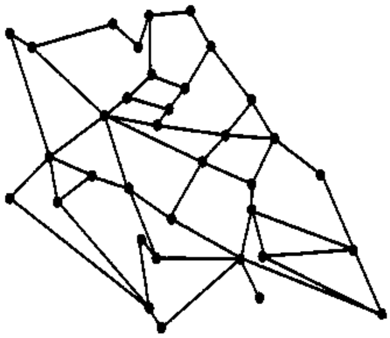


Fig. 4. User projected coordinates.

3.3 | Spatial Queries for Geometric Path Planning

Given a set of O of obstacles in 2-dimensional and 3-dimensional workspace, a starting point p_{start} and a destination point p_{start} the goal is to find the shortest path from p_{start} and p_{end} for o^M. Dijkstra algorithm (1959) is used for computing the shortest path between p_{start} and p_{end} using the visibility graph G and the visibility graph G1. Spatial queries are executed to locate the nearest neighbor and the nearest facilities.

3.4 | User Interface

User interface were created to facilitate information entry and retrieval: Adding and editing of path information, obstacle information. Using the user interface it is possible to retrieve and assess shortest path using *Fig. 5* and *Fig. 6*.

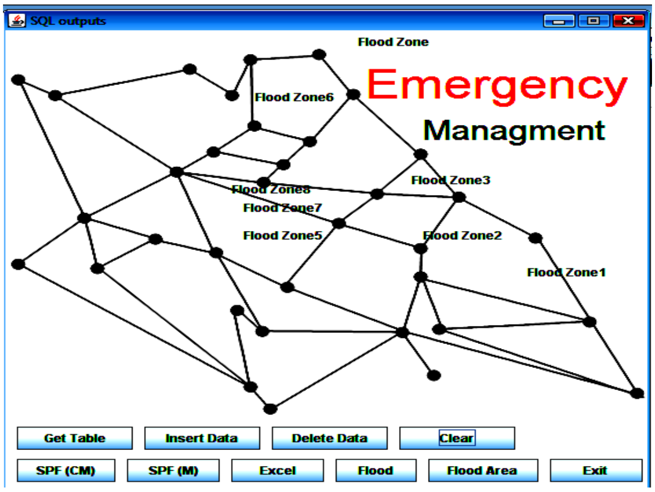


Fig. 5. User interface.

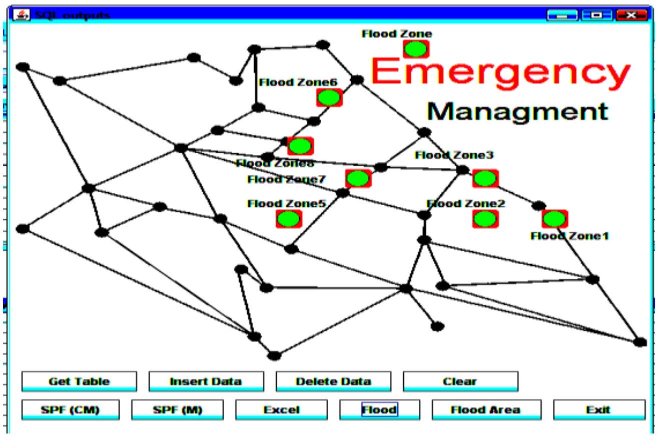


Fig. 6. Flood zones in study area.

3.5 | Geo-Spatial Maps

Maps provide interfaces to spatial system. Maps are plotted to examine the results of queries and analysis. Maps are also plotted for presentation and reports. In the present study the researcher has created general reference maps as well as thematic maps to represent spatial features shortest path analysis, closet facility.

4 | Findings

4.1 | Geo-spatial Data Model

The disaster management system is characterized by uncertainties at every stage of information processing and communication ie. data origin, data conversion, output, decision making stage. A geo-spatial data model to facilitate the development of an infrastructure for disaster management is developed. the geo-spatial data model designed and developed facilitates the disaster management activities based on data/information sharing and analysis for decision- making, coordination, command and control .

4.2 | Facilitation of Disaster Management with Geo-Spatialdata Model

Geo-Spatial data model is an initiative intended to create an environment that will enable easy access, retrieve and disseminate spatial data and information in an easy way. It is designed to assist response during a disaster, recover from the damage, manage ongoing hazardous conditions, plan and mitigate for future hazards, and

impact policy and decision making. It will also help us understand the future geographic information challenges for this application area. It is an appropriate information infrastructure framework forbringing the disaster management components together and facilitating decision making in disaster management. The main features of geo-spatial data model

I. Providing information for disaster response: activities following an emergency or disaster are called as response activities. These activities are designed to provide disaster assistance for victims. In the current study an attempt has been made to facilitate the disaster response activities by providing the best route and closest facility required at the time of emergencies.

II. Finding best route: best route means different alternate route in different situations. For example, while people are affected under disaster, they need to be rescued by any means. So the selection of the quickest route to the disaster site. hospital or shelter is very important at that moment. The network analysis was engaged to calculate the shortest way to reach in term of time and distance. The network analysis in the current study supports different objectives such as travelling quickly and travelling by the shortest route. In the current study the shortest path in terms of time in minutes as well as distance in meters is calculated using dijkstra's algorithm.

III. Closest facility: closest facility refers to anything providing a certain types of service that is closets to a given location. The disaster zone and settlement map are intersected to identify the closet facilities such as hospitals and shelter.

IV. Quick information portal: response activities can also be facilitated if the emergency responder staff gets appropriate estimated information about the damage caused before arriving to the disaster location. In the current study an attempt has been made to provide this information to the emergency responders by executing queries to the database.

5 | Geo-Spatial Data Model At Work

5.1 | Requirements and Architecture

Geographical information systems require the following four components to work with geo-spatial data: computer system, GIS software, people, data, and infrastructure. Geo-spatial data model to be mapped on to the identified scenarios needs to be supported by some basic requirements and general system architecture. As there are no standard solutions regarding the integration of heterogeneous data andservices, the system needs to remain open for further extension (functional, regional, technical). Disaster management communication and information system for handling disaster need to be realized on the basis of a Geo-Spatial infrastructure. Based on that we identified the following top requirements with respect to disaster management communication and information systems: maximum robustness/high scalability, handling of geo-spatial on each PC, integration of external data and simulation models, support for heterogeneous terminals.

5.2 | Technology

For this research scanning technique is used for digitization of mumbai island city disaster management plan. Open source map server of the google is used to obtain the satellite map in order to determine the real world coordinates. In the current prototype the disaster informationinteractive vector maps are plotted using JSP, HTML and PHP. The datasets for everyday business are created using MySQL Database contains attributes of the spatial objects required to facilitate disaster management.

5.3 | Software Customization

The model was customized to make it user friendly, interactive using JSP. PHP. User friendly graphics and symbols have teen used where ever necessary. The project windows contain view, tables and command buttons. New data can be added as well as the existing data can te edited in the database. Dynamic queries

can also te executed by the user. The methodology and the database have been customized in above mentioned solution for user friendly interface and easy implementation.

5.3 | Disaster Management Communication Andinformation System-Mumbai D Ward

During the disaster there is a need of a system that would provide updates of the spatial extent of the disaster very rapidly to all the interested parties. The Land Use map/Settlement map of D ward was analyzed to identify all the important things in the community. Using overlay technique the disaster map of the area was intersected with the Settlement map to identify the important things in the study area that could be at risk from disaster. The spatial data is also linked with a tabular data storing its attribute toprovide information required at the time of emergency. Datasets are created storing the information about all the facilitiesin the study area. Attempt is also made to calculate the shortest path between the facility and the disaster site.

6 | Conclusion

This paper tackles geo-spatial queries for facilitating disaster management activities in the presence of obstacles, given a set of entities and obstacles our aim is to answer spatial queries with respect to the obstructed distance metric, which corresponds to the length of the shortest path them through obstacles. The geo-spatial database model proposed has real life application in terms of disaster management systems. We proposed an integrated framework that answer most of the spatial queries such as closet facility, shortest path, nearest neighborhood subject to obstacle avoidance.

Author Contributions

Garima Jolly Led the conceptualization, methodology design, investigation, and drafting of the original manuscript. Also provided supervision throughout the project.

Sunita Bhati, Handled data curation and formal analysis, contributed to reviewing and editing the manuscript, and assisted with visualization.

Funding

There is no funding.

Data Availability

The design and development of spatio-temporal database models involve integrating spatial and temporal data management to address applications that involve geographic and time-based data. Here's an overview of key aspects related to the availability of data and resources for this topic.

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